EEG source imaging during two Qigong meditations

Faber, Pascal L ; Lehmann, Dietrich ; Tei, Shisei ; Tsujiuchi, Takuya ; Kumano, Hiroaki ; Pascual-Marqui, Roberto D ; Kochi, Kieko

Abstract: Experienced Qigong meditators who regularly perform the exercises "Thinking of Nothing" and "Qigong" were studied with multichannel EEG source imaging during their meditations. The intracerebral localization of brain electric activity during the two meditation conditions was compared using sLORETA functional EEG tomography. Differences between conditions were assessed using t statistics (corrected for multiple testing) on the normalized and log-transformed current density values of the sLORETA images. In the EEG alpha-2 frequency, 125 voxels differed significantly; all were more active during "Qigong" than "Thinking of Nothing," forming a single cluster in parietal Brodmann areas 5, 7, 31, and 40, all in the right hemisphere. In the EEG beta-1 frequency, 37 voxels differed significantly; all were more active during "Thinking of Nothing" than "Qigong," forming a single cluster in prefrontal Brodmann areas 6, 8, and 9, all in the left hemisphere. Compared to combined initial-final no-task resting, "Qigong" showed activation in posterior areas whereas "Thinking of Nothing" showed activation in anterior areas. The stronger activity of posterior (right) parietal areas during "Qigong" and anterior (left) prefrontal areas during "Thinking of Nothing" may reflect a predominance of self-reference, attention and input-centered processing in the "Qigong" meditation, and of control-centered processing in the "Thinking of Nothing" meditation.

DOI: https://doi.org/10.1007/s10339-012-0441-4

Originally published at:
Faber, Pascal L; Lehmann, Dietrich; Tei, Shisei; Tsujiuchi, Takuya; Kumano, Hiroaki; Pascual-Marqui, Roberto D; Kochi, Kieko (2012). EEG source imaging during two Qigong meditations. Cognitive Processing, 13(2):255-265.
DOI: https://doi.org/10.1007/s10339-012-0441-4

Cogn Process (2012) 13:255–265
DOI 10.1007/s10339-012-0441-4

RESEARCH REPORT

EEG source imaging during two Qigong meditations

Pascal L. Faber · Dietrich Lehmann · Shisei Tei · Takuya Tsujiuchi · Hiroaki Kumano · Roberto D. Pascual-Marqui · Kieko Kochi

Received: 27 September 2011 / Accepted: 19 April 2012 / Published online: 5 May 2012

Abstract Experienced Qigong meditators who regularly perform the exercises "Thinking of Nothing" and "Qigong" were studied with multichannel EEG source imaging during their meditations. The intracerebral localization of brain electric activity during the two meditation conditions was compared using sLORETA functional EEG tomography. Differences between conditions were assessed using *t* statistics (corrected for multiple testing) on the normalized and log-transformed current density values of the sLORETA images. In the EEG alpha-2 frequency, 125 voxels differed significantly; all were more active during "Qigong" than "Thinking of Nothing," forming a single cluster in parietal Brodmann areas 5, 7, 31, and 40, all in the right hemisphere. In the EEG beta-1 frequency, 37 voxels differed significantly; all were more active during "Thinking of Nothing" than "Qigong," forming a single cluster in prefrontal Brodmann areas 6, 8, and 9, all in the left hemisphere. Compared to combined initial–final no-task resting, "Qigong" showed activation in posterior areas whereas "Thinking of Nothing" showed activation in anterior areas. The stronger activity of posterior (right) parietal areas during "Qigong" and anterior (left) prefrontal areas during "Thinking of Nothing" may reflect a predominance of self-reference, attention and input-centered processing in the "Qigong" meditation, and of control-centered processing in the "Thinking of Nothing" meditation.

Keywords Meditation · LORETA · EEG · Qigong · Meditation exercise "Thinking of Nothing"

P. L. Faber (✉) · D. Lehmann · S. Tei · R. D. Pascual-Marqui · K. Kochi
The KEY Institute for Brain-Mind Research, Clinic for Affective Disorders and General Psychiatry Zurich East, University Hospital of Psychiatry, 8032 Zurich, Switzerland
e-mail: pfaber@key.uzh.ch

S. Tei · H. Kumano
Department of Stress Science and Psychosomatic Medicine, Graduate School of Medicine, The University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-8655, Japan

Present Address:
S. Tei
Department of Psychiatry, Kyoto University Graduate School of Medicine, 54 Shogoin-Kawara-cho, Sakyo-ku, Kyoto 606-8507, Japan

Present Address:
T. Tsujiuchi · H. Kumano
Department of Health Science and Social Welfare, Faculty of Human Sciences, Waseda University, Tokorozawa-City, Saitama 359-1192, Japan

Introduction

Meditative states belong to those altered states of consciousness (Tart 1969; Dietrich 2003; Vaitl et al. 2005) that can be reached voluntarily, without drugs, by doing exercises (practices) which have been established in the different traditions of meditation. The traditions use very different repertories of meditation exercises. Moreover, within a given tradition, typically several different exercises are done by the meditators.

Different exercises of a given meditation tradition produce meditative states that differ in physiological measures, for example, oxygen uptake "VO2" (Benson et al. 1990), electrocardiogram (Peng et al. 2004), and autonomic patterns (Travis 2001), as well as in psychological measures, for example, pain sensation (Perlman et al. 2010), mood and anxiety (Zeidan et al. 2010), attention (Jha et al. 2007), and subjective experience (Wang et al. 2011).

EEG measures also yielded various differences between different exercises within a given tradition: in Buddhist meditation (power spectra: Benson et al. 1990; source localization: Lehmann et al. 2001), in mindfulness-concentration meditation (power spectra: Dunn et al. 1999), in Qigong (power spectra: Pan et al. 1994), in Shaolin Dan Tian breathing (power and coherence: Chan et al. 2011), and in Transcendental Meditation (power spectra, coherence, and source localization: Travis 2001, 2011; Travis et al. 2010; see also Travis and Shear 2010). On the other hand, Sun et al. (1984) reported that there was no difference in results between QiGong exercises. Given the variety of meditation traditions, meditation exercises, and techniques of EEG recording and analysis, the reported results expectedly varied widely (see also Cahn and Polich 2006).

As to EEG studies on QiGong, the eight papers that are available to us show little agreement and some direct contradictions of results during meditation compared to rest or controls. Going through the EEG frequency bands, we note the following: Two of the studies found theta increase (Pan et al. (1994; Minegishi et al. 2009), two found frontal alpha-1 increase (Zhang et al. 1988; Qin et al. 2009), one found alpha-2 increase (Minegishi et al. 2009), one found frontal alpha full band increase (Sun et al. 1984), one found occipital alpha full band increase (Lee et al. 1997), one found right frontal-temporal alpha full band decrease (Yang et al. 1994), one found beta-1 increase (Minegishi et al. 2009), one found beta-2 increase (Itoh et al. 1996), and one found right frontal-temporal beta full band decrease (Yang et al. 1994). Assuming that all reports concerned the exercise that leads to the optimal meditative state, the irritating lack of agreement partly might be due to different EEG analysis strategies as also mentioned above. Enlarging the result base appears of paramount importance for clarification.

We had the possibility to record EEG from experienced Qigong meditators who regularly perform two exercises of their meditation tradition, doing first "Thinking of Nothing" and thereafter "Qigong" (that involves slow arm movements) to reach the desired optimal meditative states of consciousness. Because the meditators were not willing to reverse their habitual sequence when we proposed such a reversal in order to eliminate sequence effects, we conclude that getting into "Thinking of Nothing" is the prerequisite for doing "Qigong." The latter evidently is the exercise that leads to the desired optimal state of QiGong meditation. This conclusion is supported by the meditators' spontaneous reports that they reached a deeper state of meditation during "Qigong."

We decided to contribute to the collection of brain electric effects of different QiGong exercises by applying the electric source imaging method "Low Resolution Electromagnetic Tomography" (LORETA, Pascual-Marqui 2002; Pascual-Marqui et al. 1994, 2002) to our data in order to determine the intracerebral localization and strength of brain electric activity of inhibiting and facilitating character. LORETA brain electric functional imaging analysis uses intracerebral source modeling and thereby avoids the ambiguities of localization and strength that are inherent in conventional analyses of head-surface EEG data because the latter depends on the chosen reference location.

It would be desirable to classify the two QiGong exercises in a general scheme of meditation states; we note that the exercises of our meditators are only two specific practices of a large number of different sub-traditions and techniques known as QiGong. Early proposals of meditation taxonomies referred to a trophotropic-ergotropic or hypoarousal-hyperarousal axis (Fischer 1971; Gellhorn and Kiely 1972) and did not mention QiGong. Later schemes proposed two or three distinct categories. Based on Buddhist traditions of meditation was the concentration *versus* mindfulness classification by Davidson and Goleman (1977)—mindfulness was exclusively emphasized by Kabat-Zinn (1982)—and the focused attention *versus* open monitoring classification (Dunn et al. 1999; Lutz et al. 2008; Raffone and Srinivasan 2010), as well as the concentration—mindfulness—grasping classification by Mikulas (1990); none of these mentioned QiGong. Cahn and Polich (2006) offered a review that distinguished concentration from mindfulness meditation, and accepted Pan et al.'s (1994) report on "concentrative QiGong" as such while concluding that Pan et al.'s "non-concentrative QiGong" must be mindfulness. In fact, Pan et al.'s paper does not give a description of the two meditation exercises beyond their labeling. We note, however, that the Buddhist meditation-based dichotomic or trichotomous schemes do not address the ultimate desired optimal meditation state that has been described across meditation traditions (Fischer 1971; Davidson 1976; Newberg and Iversen 2003) in terms such as all-oneness, bliss, oceanic feeling, transcending, or expanded consciousness. Travis and Shear (2010) include "transcending" in their three-way classification of focused attention, open monitoring, and automatic self-transcending. As to QiGong, however, these authors classify Pan et al. (1994) "concentrative QiGong" condition as "open monitoring," contrary to Cahn and Polich's (2006) acceptance of "concentration" (see above) as also done by Baijal and Srinivasan (2010) and Cahn et al. (2010). Travis and Shear's (2010) classification as "open monitoring" is due to their EEG frequency band-based three-way classification: gamma and beta-2 indicates focused attention, theta indicates open monitoring, and alpha-1 indicates "automatic self-transcending" as known in Transcendental Meditation. In sum, the overview about classification schemes shows that the minimal attention and the controversial entries about QiGong in the proposed distinctions between meditation techniques does not indicate useful conclusions about our present material (see also Baerentsen et al. 2010).

We analyzed the multichannel EEG recordings obtained from our experienced Qigong meditators during their exercises of "Thinking of Nothing" and "Qigong" and no-task resting, using sLORETA functional EEG tomography (Pascual-Marqui 2002; Pascual-Marqui et al. 2002). We compared the intracerebral localization and strength of the sources of brain electric activity during the two meditation exercises and examined how they differed from no-task resting.

We hypothesized (1) that the two meditation states "Thinking of Nothing" and "Qigong" are different in their brain electric signature, (2) that "Qigong" shows activity in motor areas, and (3) that "Thinking of Nothing" and "Qigong" differ from no-task resting in the same direction.

The present study thus aims at providing insights into brain electric mechanisms of different QiGong meditation exercises using the above-mentioned LORETA analysis that yields non-ambiguous results, thereby enlarging a reliable database for future more complete classifications of meditation exercises.

Materials and methods

Participants

Among the members of Master Feng-San Lee's Qigong Center "Meimen" in Taipei, experienced meditators were invited to participate in the study. During a visit of the meditator group to Tokyo, EEG during meditations could be recorded from 10 meditators; the data of two had to be omitted (technical problems in one case, a strong headache during the recording in the other). Thus, data of eight meditators were available for analysis (mean age: 41.5 years, SD = 10.4, range: 30–56, 3 males, education level: 2 high school, 6 university graduates). The eight meditators had an average meditation experience of 11.5 years (SD = 8.8, range: 3–30), and all meditated regularly for approximately one hour each day.

All meditators were self-declared right-handers and reported no earlier or current psychiatric illness, no head trauma and no drug usage, and they did not take centrally active medication. After receiving complete information about the study, all meditators gave their written consent. The Ethics Committee of The University of Tokyo approved the study (#1364) that follows the standards of the Declaration of Helsinki laid down in 1964.

EEG recording

The EEG was recorded in a room of the hotel where the meditators stayed during their visit to Tokyo. The participants were seated on a comfortable chair. Nineteen EEG electrodes were applied at Fp1/2, F3/4, F7/8, Fz, T3/4, C3/4, Cz, T5/6, P3/4, Pz, O1/2 of the International 10/20 System (Jasper, 1958) using a Neuroscan electrode cap. The EEG recording was done with a portable 24-channel EEG acquisition system (TEAC AP1000). All impedances were kept below 5 kΩ. The left ear was used as a reference for the EEG channels. The EOG was recorded from electrodes at the outer left canthus and under the right eye. One more electrode on the neck recorded muscle activity. Using a recording high pass filter of 0.05 Hz and a low pass filter of 100 Hz, the EEG data were digitized at 200 samples/sec per channel.

Recording conditions

1. Initial Resting (4 min): The task-free eyes-closed resting condition was recorded at the beginning of the recording session: 20 s eyes open, 40 s eyes closed, repeated four times.

The meditators then performed their three standard meditation exercises (Yuasa 1990, p. 114 and p. 136) as described here, followed by a final resting period:

2. Breath Counting (10 min): A preparatory exercise to calm the mind and the body while concentrating on nasal air flow. This preparatory condition was not included in the present analysis.
3. "Thinking of Nothing" (10 min): A meditation exercise. The practitioner is "Thinking of Nothing." The focus is on trying not to think of anything or feel anything, physically, to let the body relax, and mentally, to try to "dissolve into emptiness."
4. "Qigong" (10 min): A meditation exercise. The practitioner is performing "Qigong," which means doing slow arm movements in synchrony with his/her breathing while continuing to think of nothing, reaching higher sensory awareness, transcending. The arm movements are done at a very slow rate, as low as about two per minute.
5. Final Resting (4 min): The task-free eyes-closed resting condition was repeated at the end of the recording session: 20 s eyes open, 40 s eyes closed, repeated four times.

The preparatory and meditation conditions were done with closed eyes, following the meditators' daily practice.

The experimenter verbally cued the start and end of each condition.

Data conditioning

EEG data of the resting conditions (1) and (5) and of the meditation conditions (3) and (4) were analyzed. Off-line, the data were parsed into 2-second epochs; all epochs were inspected on a PC screen for eye-, muscle-, and technical artifacts; all artifact-free epochs were selected for analysis. An earlier selection of resting (1) data was used in Tei et al. 2009. An average of 88.6 (SD = 94.4; range: 13–254) 2-second epochs per participant was available for the meditation condition (3), and 91.8 (SD = 80.5; range: 18–230) for meditation condition (4). For initial resting (1), the average was 45.8 epochs (SD = 16.9; range: 30–74) per participant, for final resting (5) 43.1 (SD = 19.0; range: 7–72) epochs.

Frequency band-wise LORETA analysis

Low Resolution Electromagnetic Tomography (LORETA; Pascual-Marqui et al. 1994, 1999, 2002; Pascual-Marqui 2002) solves the inverse problem of computing the 3-dimensional intracortical localizations of the brain electric generators that produced the potential distribution that were measured on the head surface. It does this by finding the smoothest of all possible solutions without using any a priori assumptions as to number, location, or orientation of the generators. Published validation for the LORETA method has shown for instance excellent localization agreement in multimodal imaging studies with functional MRI (Mulert et al. 2004; Vitacco et al. 2002), structural MRI (Worrell et al. 2000), and PET (Dierks et al. 2000; Zumsteg et al. 2005). Also, validation in humans based on accepting the information provided by intracranial recordings as “ground truth” has been reported in several papers (Zumsteg et al. 2006a, b; Yang et al. 2011).

sLORETA (Pascual-Marqui 2002; Pascual-Marqui et al. 2002; available free from http://www.uzh.ch/keyinst/loreta.htm) was used to analyze the head-surface EEG data into brain functional tomographic images. The sLORETA solution space covers the cortical grey matter, sampled at 5 mm resolution, yielding a total of 6,239 voxels for which current density values are computed. The analysis was done separately for the statistically independent frequency bands (Kubicki et al. 1979; Niedermeyer and Lopes da Silva 2005) of delta (1.5–6 Hz), theta (6.5–8 Hz), alpha-1 (8.5–10 Hz), alpha-2 (10.5–12 Hz), beta-1 (12.5–18 Hz), beta-2 (18.5–21 Hz), and beta-3 (21.5–30 Hz); a gamma frequency band (35–44 Hz) was added.

sLORETA functional images were computed for each subject and condition separately in each of the eight frequency bands. The sLORETA functional images were frequency band-wise normalized (using the program option “time frame wise normalized”), that is, for each subject, the average of the power values over all sLORETA voxels was scaled to unity for each frequency band. Such scaling permits to exclusively detect differences in the spatial distribution of the activity between conditions across subjects while omitting the effects of irrelevant inter-individual differences in overall strength of the head-surface recorded voltages.

Brain electric activity differences between conditions were assessed using t statistics on the log-transformed sLORETA images. Correction for multiple testing after Nichols and Holmes (2002) was applied. The sLORETA voxels are attributed to Brodmann areas (BA) based on their MNI coordinates.

The possible effects of elapsed time

The experimental protocol clearly involved a potential time effect in that the sequence of recording conditions was fixed, following the meditation routines of the participants; they habitually first did the initiating breath counting, then the meditation states of “Thinking of Nothing,” followed by “Qigong.” Theoretically desirable intermittent resting conditions were not acceptable to the meditators.

We tested the sLORETA tomography images of initial resting versus final resting for time effects: There were no significant differences (corrected for multiple testing) in any of the eight frequency bands. Therefore, the current density values were averaged across the two resting conditions for each subject as “mean rest.”

Results

Differences between “Qigong” and “Thinking of Nothing”

The strength of voxel activation differed at $p < 0.05$ (after correction for multiple testing) between the meditation conditions “Thinking of Nothing” and “Qigong” only in the frequency bands of alpha-2 (critical $t > 6.286$ for corrected $p < 0.05$; best observed $p(\text{corrected}) = 0.0074$ was at $t = 7.966$) and beta-1 (critical $t > 6.423$ for corrected $p < 0.05$; best observed $p(\text{corrected}) = 0.026$ was at $t = -8.171$). These results are illustrated in the glass brain head views of Fig. 1. The other six frequency bands (delta, theta, alpha-1, beta-2, beta-3, and gamma) did not show significant differences after correction for multiple testing.

In the alpha-2 frequency band, all 125 voxels that differed significantly were more active in “Qigong” than in “Thinking of Nothing”; they formed a single cluster in the parietal Brodmann areas 5 ($N = 25$), 7 ($N = 84$), 31 ($N = 14$), and 40 ($N = 2$), all in the right hemisphere (Fig. 1, upper row).

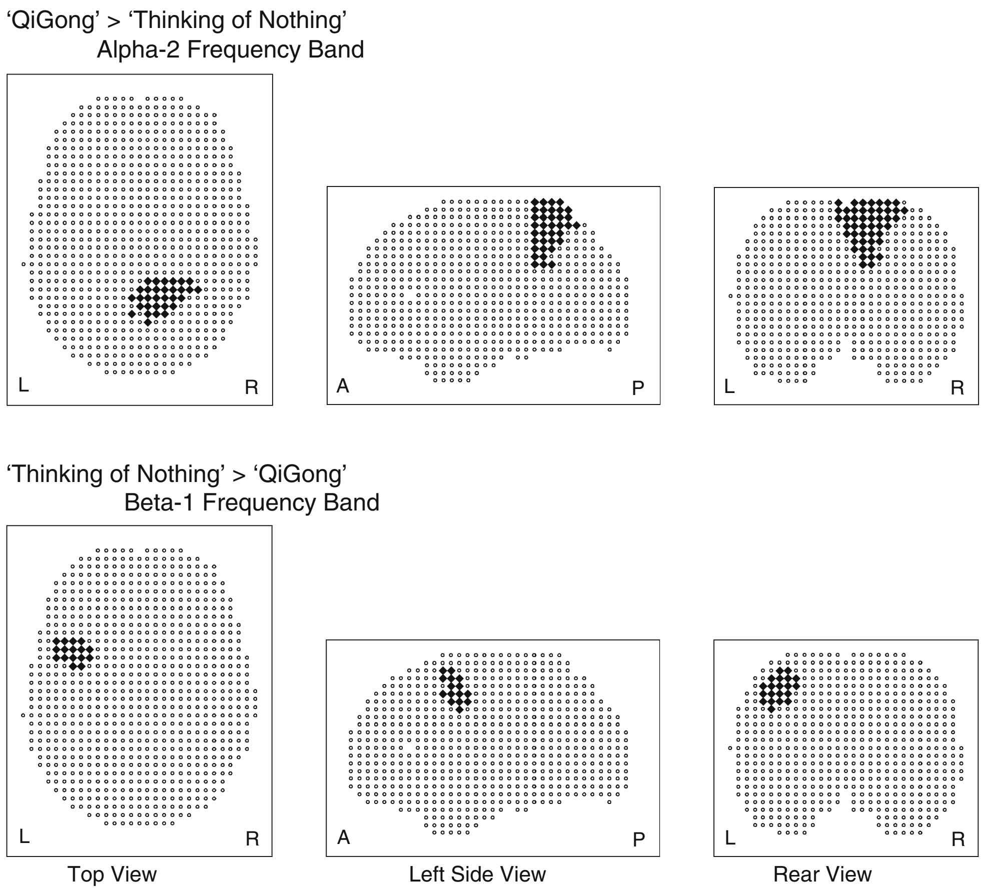

Fig. 1 Comparison of brain activity during "Qigong" and "Thinking of Nothing." Glass brain views, from *left* to *right*: axial, sagittal, and coronal views. *Upper row*: "Qigong" had stronger activity than "Thinking of Nothing" in the alpha-2 EEG frequency band (10.5–12 Hz). *Lower row*: "Thinking of Nothing" had stronger activity than "Qigong" in the beta-1 EEG frequency band (12.5–18 Hz). *Dark* voxels: Differences between the meditative states at $p < 0.05$ after correction for multiple testing. *Light* voxels: sLORETA voxel space (MNI; *left* to *right*: −70 to +70 mm; posterior to anterior: −100 to +65 mm; inferior to superior: −45 to +70 mm)

There was no significant correlation (corrected for multiple testing) of alpha-2 voxel strength during "Qigong" (as well as during "Thinking of Nothing") with years of meditation experience or with age.

In the beta-1 frequency band, all 37 voxels that differed significantly were more active in "Thinking of Nothing" than in "Qigong"; they formed a single cluster in the frontal Brodmann areas 6 ($N = 31$), 8 ($N = 3$) and 9 ($N = 3$), all in the left hemisphere (Fig. 1, lower row).

As above for alpha-2, there was no significant correlation (corrected for multiple testing) of beta-1 voxel strength during "Qigong" (as well as during "Thinking of Nothing") with years of meditation experience or with age.

The general trend of the differences

The two EEG frequency bands of interest yielded significant differences between meditation conditions in different brain regions as reported above. Reducing the statistical thresholding showed that these different brain regions reported above represent a general trend in both frequency bands: At uncorrected values of $p < 0.05$ ($df = 7$, $t > 2.36$), "Qigong" showed stronger activity than "Thinking of Nothing" in large posterior areas consisting in the alpha-2 band of 1993 of all 6,239 LORETA voxels and in the beta-1 band of 1,067 of all 6,239 LORETA voxels (Fig. 2a), while "Thinking of Nothing" showed stronger activity than "Qigong" in large anterior areas consisting in the alpha-2 band of 2,513 of all 6,239 LORETA voxels and in the beta-1 band of 1,210 of all 6,239 LORETA voxels (Fig. 2d). In other words, about 2/3 of all voxels reached $p < 0.05$ in the alpha-2 band, and about 1/3 of all voxels in the beta-1 band.

Differences between the two meditation states and no-task resting

To clarify how the brain regional activations in the two frequency bands of interest differed between the practitioners' resting state and the two meditation states, mean

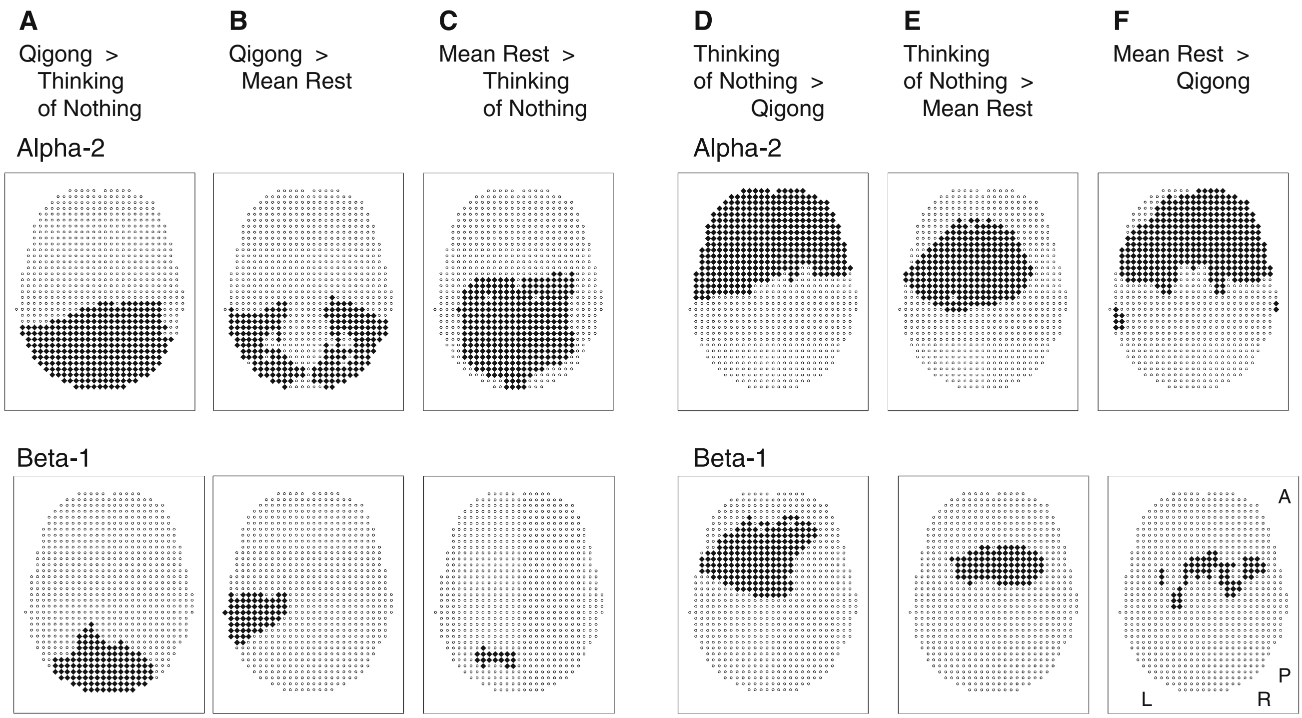

Fig. 2 Comparison of brain activity during the conditions "Qigong," "Thinking of Nothing," and no-task rest in the two EEG frequency bands (alpha-2 and beta-1) that showed significant differences between the two meditative states. Glass brain axial views. *Dark* voxels: Differences at $p < 0.05$ (not corrected for multiple testing). *Light* voxels: sLORETA voxel space (MNI; *left* to *right*: −70 to +70 mm; posterior to anterior: −100 to +65 mm)

rest was tested against "Qigong" and against "Thinking of Nothing." There were no significant results after correction for multiple testing. However, at uncorrected $p < 0.05$, in both frequency bands, "Qigong" differed from rest with stronger activity in more posterior regions compared to where "Thinking of Nothing" differed from rest (compare Fig. 2b to Fig. 2e, and Fig. 2c to Fig. 2f). In other words, for both frequency bands of interest, Fig. 2 shows that "Qigong" engaged posterior areas, while "Thinking of Nothing" engaged anterior areas.

The number of qualifying voxels involved in the differences was much higher in the alpha-2 band than in the beta-1 band as shown in Table 1. Further, Fig. 2 and Table 1 show that the general activity level of the no-task resting state was between the two meditation states, differing from either one, but in opposite directions.

Table 1 Numbers of voxels different at $p < 0.05$ (uncorrected) illustrated in Fig. 2

	A QG>TN	B QG>rest	C rest>TN	D TN>QG	E TN>rest	F rest>QG
A-2	1,993	656	1,215	2,513	1,754	967
B-1	1,067	315	27	1,210	141	227

A-2 alpha-2 frequency, B-1 beta-1 frequency, *QG* "Qigong"

TN "Thinking of Nothing," *rest* mean rest. *A-F* columns of Fig. 2

Discussion

Intracerebral source imaging showed that the brain electric activity clearly differed between the two forms of meditation, the exercise of "Qigong" versus the exercise of "Thinking of Nothing" in the QiGong tradition, thus supporting hypothesis (1).

"Qigong" showed significantly stronger activity than "Thinking of Nothing" in the EEG alpha-2 frequency band in a single cluster of voxels in the right parietal lobe.

EEG alpha frequency activity reportedly increases during tasks not requiring attention to the environment, that is, during internally directed attention (Cooper et al. 2003; Palva and Palva 2007), specifically parietal alpha (Ray and Cole 1985). Increased alpha was observed in particular during working memory performance (Klimesch 1999; Jensen et al. 2002; Palva and Palva 2007; at the parietal-occipital junction: Tuladhar et al. 2007). Thus, the earlier interpretation of alpha generally representing "idling" has given way to the view that alpha indicates the suppression of visual input in order to free capacity for other processing (e.g., Tuladhar et al. 2007).

The right parietal significant cluster included voxels in BAs 5, 7, 31, and 40. Most voxels were in BAs 5 and 7 that constitute the secondary sensorimotor cortex; this cortex, however, also is involved in higher functions such as the perception of the personal space (Lloyd et al. 2006), attention (Jovicich et al. 2001; Luks and Simpson 2004; Caplan et al. 2006) as well as memory functions which were early on observed in these areas (personal space: Tulving et al. 1994; spatial memory: Constantinidis and Steinmetz 1996; intention coding: Snyder et al. 1997) and which are of pivotal importance for self-reference processes (see Kihlstrom et al. 2003; Conway 2005). Also, similar to BA 5 and BA 7, BA 31 activity has been associated with self-referenced cognition (third versus first person perspective: Ruby and Decety 2004), in addition to evaluative judgments (Zysset et al. 2002). The range of functions ascribed to BA 40 include past-related information processing like recollection of previously experienced events (Tulving et al. 1994) and reestablishing executive control over previously automatized behavior (Kübler et al. 2006). In sum, embedded into the standard function of input integration in the parietal areas, self-referencing recollection and attentive control of earlier learned behavior experience is stronger in "Qigong" than in "Thinking of Nothing."

On the other hand, "Thinking of Nothing" showed significantly stronger activity than "Qigong" in the EEG beta-1 frequency band in a single cluster of voxels in the left frontal lobe.

EEG beta frequency activity generally indicates activation–excitation–facilitation (Lopes da Silva 1991) and increases during attention (Wrobel 2000; in particular beta-1: Kisley and Cornwell 2006; Basile et al. 2010) as well as with alertness (Makeig and Inlow 1993; Lehmann et al. 1995) and during various mental activities, for example, during mental representation of objects (Tallon-Baudry and Bertrand 1999).

The significant left frontal cluster was located mostly in BA 6, with some voxels in the neighboring BAs 8 and 9. BA 6—although being a premotor or supplementary motor area—frequently is involved without motor activity in cognitive functions (imagery: Mellet et al. 1996; comparisons: Dehaene et al. 1996; numerical, verbal, and spatial tasks: Hanakawa et al. 2002; encoding-recognition: Ranganath et al. 2003; deductive reasoning: Reverberi et al. 2007). BAs 8 and 9 likewise are activated during higher functions such as executive control (Sarazin et al. 1998; Kübler et al. 2006), inductive reasoning (Goel et al.1997), and memory functions (Okuda et al. 2000; Ranganath et al. 2003; Babiloni et al. 2005). Thus, "Thinking of Nothing" was associated with cogitation and memories within the prefrontal areas which also supervise motor control processing. This may well reflect the recurring attempts to skip such mentations while pursuing the goal of the "Thinking of Nothing" meditation. We note that BAs 6, 8, and 9 were not parts of the left frontal core area of abstract thought reported earlier (Lehmann et al. 2010) and that they did not include the classical language areas BA 45 and 46, thereby making it unlikely that verbalizations of abstract concepts were involved.

Our hypothesis (2) that "Qigong" might involve prominent activity of frontal motor areas was not supported by the present results. The execution of the slow movements might have been so strongly automated that it needed only an undetectable engagement of central control.

We had formed hypothesis (3) that brain electric activity during "Qigong" might be an increase of what occurs during "Thinking of Nothing," because the meditators said that it is necessary to do "Thinking of Nothing" before doing "Qigong." But, hypothesis (3) was not supported by the results: The results for no-task rest were positioned between the two meditations. The differences within the two frequency bands between the two meditations at the reduced thresholding of $p < 0.05$ clearly show (Fig. 2a, d) the stronger posterior activation during "Qigong" and the stronger anterior activation during "Thinking of Nothing," neatly separated in space, and clearly reflected by corresponding differences from no-task rest: stronger posterior activation during "Qigong," stronger anterior activation during "Thinking of Nothing" (Fig. 2b, e).

We appreciate that no-task rest in the meditators may not be quite the same as no-task rest in a control population since experienced meditators reportedly show persisting meditation effects in their brain electric activity at rest when they do not meditate (Tebecis 1975; Itoh et al. 1996; Newberg et al. 2001; Davidson et al. 2003; Lutz et al. 2004; Aftanas and Golosheykin 2005; Travis and Arenander 2006; Faber et al. 2008; Tei et al. 2009). At any case, no-task rest in our practitioners implies the absence of willfully intended meditation and therefore appears to be a valid meditation-neutral reference condition.

Meditation experience as well as age of our meditators did not correlate with the results. As reports of correlations between brain activity and meditation experience vary widely over studies and measures, our results will increase the knowledge base but are not surprising. For example, Berkovich-Ohana et al. (2012) in their EEG gamma band study observed no correlation with experience. Cahn et al. (2010) reported expertise-dependent increase in gamma band activity, but no effect on theta and beta. Murata et al. (1994) reported theta frequency waves increase with experience while alpha waves did not. Lutz et al. (2004) observed a significant correlation with experience in only one of six gamma band measures. Travis and Arenander (2006) reported increased alpha-1 coherence with experience. Interestingly, Brefczynski-Lewis et al. (2007) noted that the fMRI result dependence on experience shows an inverted U-shaped distribution, that is, that eventually, very much experience has minimal effects on results, and that many brain regions showed significant negative correlation with hours of practice.

The present study yielded significant increases during "Qigong" in two of the eight EEG frequency bands, in alpha-2 (posterior) and beta-1 (anterior), thereby partially agreeing with two of the eight QiGong EEG reports, that is, with the reported general increase in alpha-2 (Lee et al. 1997; Minegishi et al. 2009) and beta-1 power (Minegishi et al. 2009), but disagreeing with the other six QiGong reports (see introduction). Neither theta nor gamma frequencies were significant in the present study although they were often involved in reported EEG changes during meditation which, however, vary widely over analysis approaches and traditions. At first, reports of alpha dominated the field, but fast beta was also noted (e.g., Das and Gastaut 1957 in Yoga). Later, in addition to alpha and beta (including 40 Hz), theta occurrence was reported (e.g., in Zen: Kasamatsu and Hirai 1966; in Transcendental Meditation: Wallace et al. 1971; Banquet 1973; Hebert and Lehmann 1977; more recently, for example, in non-directive meditation: Lagopoulos et al. 2009 and in concentrative meditation: Baijal and Srinivasan 2010). It is noteworthy that of the 78 experienced meditators in Hebert and Lehmann (1977), only 21 showed the theta burst phenomenon. Lately, the gamma frequency band attracted particular attention during meditation (Lehmann et al. 2001; Lutz et al. 2004; Cahn et al. 2010; Lavallee et al. 2011; Berkovich-Ohana et al. 2012). In this literature, each study examined meditators from one tradition with a specific analysis approach; the results do not indicate clear EEG differences between meditation traditions. It appears that Cahn and Polich's (2006) statement that "differences among meditative practices have not been well established" still holds. In fact, we observed EEG changes that were common during meditation in five traditions (Lehman et al. 2012), that is, a generally reduced functional connectivity (intracerebral lagged EEG coherence) in all eight frequency bands, in support of Newberg and Iversen (2003) that "the end results of many practices of meditation are similar" (see also Fischer 1971; Davidson 1976).

The basic feature of our present results, the increase in posterior brain activation during "Qigong" versus "Thinking of Nothing", or no-task rest was also observed for optimal meditative states in other traditions (versus rest: Lou et al. 1999; Berkovich-Ohana et al. 2012; versus controls: Cahn et al. 2010; sidhi versus transcending: Travis 2011), contrary to other studies that reported increases in frontal activity (e.g., Davidson et al. 2003; Hölzel et al. 2007; Davanger et al. 2010; Engström and Söderfeldt 2010; Lagopoulos et al. 2009; Travis et al. 2010). The usual issues of different measurement and analysis methods, of sometimes fundamentally different concepts of result interpretation, and of different meditation techniques prevent binding conclusions.

In sum, our source imaging results show stronger activation of posterior right parietal areas during "Qigong" and of anterior left prefrontal areas during "Thinking of Nothing," reflecting a predominance of self-reference, attention- and input-centered information processing during the "Qigong" meditation and of control-centered information processing during the "Thinking of Nothing" meditation. One may speculate that the "Thinking of Nothing" exercise leads to such a strong degree of automation of attention to no-thinking that the participating processes become undetectable in the subsequent, new, and deeper meditation state of "Qigong" that the meditators claim to imply transcending.

The shortcoming of this EEG meditation study is that it did not include—as many other meditation studies—subjective ratings of the experienced quality of the meditations, and no reports of private thought contents during the meditations, and no assessment of the meditators' personality parameters. Why are there so few systematic reports on subjective experience during meditation? For example, subjective responses in questionnaires filled out after a meditation study turned out to be impossible to quantitate or analyze (Newberg et al. 2001). One could suspect that (a) the unusual meditation experiences might be difficult to verbalize, that (b) they probably are distorted by habitual terminology because of their unfamiliar mystic character, that (c) they often are obviously disfigured by poetic embellishments or meditation tradition-specific standard terminology, and that (d) they might be too varied across individuals to easily show common characteristics. Subjective data (e.g., Hebert and Lehmann 1977; Piron 2003; Hölzel and Ott 2006; Aftanas and Golocheikine 2001; Travis 2001; Baijal and Srinivasan 2010; Wang et al. 2011; Hasenkamp et al. 2012), however, could be very useful for comparisons between studies, and for sorting out brain states of different cogitations and of depth or quality of meditation, thereby more exactly identifying the involved brain functions.

Acknowledgments This work was supported in part by grant Nr. 44/06 from the Bial Foundation, S. Mamede do Coronado, Portugal. We thank Qigong Master Feng-San Lee for the possibility to contact the meditators of his group and Mitsumasa Kawakami for helpful comments to experimental settings.

References

Aftanas LI, Golocheikine SA (2001) Human anterior and frontal midline theta and lower alpha reflect emotionally positive state

and internalized attention: high-resolution EEG investigation of meditation. Neurosci Lett 310(1):57–60
Aftanas L, Golosheykin S (2005) Impact of regular meditation practice on EEG activity at rest and during evoked negative emotions. Int J Neurosci 115(6):893–909
Babiloni C, Ferretti A, Del Gratta C, Carducci F, Vecchio F, Romani GL, Rossini PM (2005) Human cortical responses during one-bit delayed-response tasks: an fMRI study. Brain Res Bull 65(5): 383–390
Baerentsen KB, Stødkilde-Jørgensen H, Sommerlund B, Hartmann T, Damsgaard-Madsen J, Fosnaes M, Green AC (2010) An investigation of brain processes supporting meditation. Cogn Process 11(1):57–84
Baijal S, Srinivasan N (2010) Theta activity and meditative states: spectral changes during concentrative meditation. Cogn Process 11(1):31–38
Banquet JP (1973) Spectral analysis of the EEG in meditation. Electroenceph Clin Neurophysiol 35(2):143–151
Basile LF, Lozano MD, Alvarenga MY, Pereira JF, Machado S, Velasques B, Ribeiro P, Piedade R, Anghinah R, Knyazev G, Ramos RT (2010) Minor and unsystematic cortical topographic changes of attention correlates between modalities. PLoS ONE 5(12):e15022
Benson H, Malhotra MS, Goldman RF, Jacobs GD, Hopkins PJ (1990) Three case reports of the metabolic and electroencephalographic changes during advanced Buddhist meditation techniques. Behav Med 16(2):90–95
Berkovich-Ohana A, Glicksohn J, Goldstein A (2012) Mindfulness-induced changes in gamma band activity – Implications for the default mode network, self-reference and attention. Clin Neurophysiol 123(4):700–710
Brefczynski-Lewis JA, Lutz A, Schaefer HS, Levinson DB, Davidson RJ (2007) Neural correlates of attentional expertise in long-term meditation practitioners. Proc Natl Acad Sci USA 104(27): 11483–11488
Cahn BR, Polich J (2006) Meditation states and traits: EEG, ERP, and neuroimaging studies. Psychol Bull 132(2):180–211
Cahn BR, Delorme A, Polich J (2010) Occipital gamma activation during Vipassana meditation. Cogn Process 11(1):39–56
Caplan JB, Luks TL, Simpson GV, Glaholt M, McIntosh AR (2006) Parallel networks operating across attentional deployment and motion processing: a multi-seed partial least squares fMRI study. Neuroimage 29(4):1192–1202
Chan AS, Cheung MC, Sze SL, Leung WW, Shi D (2011) Shaolin dan tian breathing fosters relaxed and attentive mind: a randomized controlled neuro-electrophysiological study. Evid-Based Compl Altern Med 2011:180704 (11 pages)
Constantinidis C, Steinmetz M (1996) Neuronal activity in posterior parietal area 7a during the delay periods of a spatial memory task. J Neurophysiol 76:1352–1355
Conway MA (2005) Memory and the self. J Mem Lang 53(4): 594–628
Cooper NR, Croft RJ, Dominey SJJ, Burgess AP, Gruzelier JH (2003) Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. Int J Psychophysiol 47:65–74
Das NN, Gastaut H (1957) Variation de l'activité électrique du cerveau, du coeur et des muscles squelettiques au cours de la méditation et de l'extase yogique. Electroenceph Clin Neurophysiol (Suppl 6):211–219
Davanger S, Ellingsen O, Holen A, Hugdahl K (2010) Meditation-specific prefrontal cortical activation during acem meditation: an fMRI study. Percept Mot Skills 111(1):291–306
Davidson JM (1976) The physiology of meditation and mystical states of consciousness. Perspect Biol Med 19(3):345–379
Davidson RJ, Goleman DJ (1977) The role of attention in meditation and hypnosis: a psychobiological perspective on transformations of consciousness. Int J Clin Exp Hyp 25:291–308
Davidson RJ, Kabat-Zinn J, Schumacher J, Rosenkranz M, Muller D, Santorelli SF, Urbanowski F, Harrington A, Bonus K, Sheridan JF (2003) Alterations in brain and immune function produced by mindfulness meditation. Psychosom Med 65(4):564–570
Dehaene S, Tzourio N, Frak V, Raynaud L, Cohen L, Mehler J, Mazoyer B (1996) Cerebral activations during number multiplication and comparison: a PET study. Neuropsychologia 34:1097–1106
Dierks T, Jelic V, Pascual-Marqui RD, Wahlund LO, Julin P, Linden DEJ, Maurer K, Winblad B, Nordberg A (2000) Spatial pattern of cerebral glucose metabolism (PET) correlates with localization of intracerebral EEG-generators in Alzheimer's disease. Clin Neurophysiol 111:1817–1824
Dietrich A (2003) Functional neuroanatomy of altered states of consciousness: the transient hypofrontality hypothesis. Conscious Cogn 12(2):231–256
Dunn BR, Hartigan JA, Mikulas WL (1999) Concentration and mindfulness meditations: unique forms of consciousness? Appl Psychophys Biof 24(3):147–165
Engström M, Söderfeldt B (2010) Brain activation during compassion meditation: a case study. J Altern Complem Med 16(5):597–599
Faber PL, Steiner ME, Lehmann D, Pascual-Marqui RD, Jäncke L, Esslen M, Gianotti LRR (2008) Deactivation of the medial prefrontal cortex in experienced Zen meditators. Brain Topogr 20:172
Fischer R (1971) A cartography of the ecstatic and meditative states. Science 174(4012):897–904
Gellhorn E, Kiely WF (1972) Mystical states of consciousness: neurophysiological and clinical aspects. J Nerv Ment Dis 154(6):399–405
Goel V, Gold B, Kapur S, Houle S (1997) The seats of reason? An imaging study of deductive and inductive reasoning. NeuroReport 8(5):1305–1310
Hanakawa T, Honda M, Sawamoto N, Okada T, Yonekura Y, Fukuyama H, Shibasaki H (2002) The role of rostral Brodmann area 6 in mental-operation tasks: an integrative neuroimaging approach. Cereb Cortex 12(11):1157–1170
Hasenkamp W, Wilson-Mendenhall CD, Duncan E, Barsalou LW (2012) Mind wandering and attention during focused meditation: a fine-grained temporal analysis of fluctuating cognitive states. Neuroimage 59(1):750–760
Hebert R, Lehmann D (1977) Theta bursts: an EEG pattern in normal subjects practicing the transcendental meditation technique. Electroenceph Clin Neurophysiol 42(3):397–405
Hölzel B, Ott U (2006) Relationships between meditation depth, absorption, meditation practice, and mindfulness: a latent variable approach. J Transpers Psychol 38(2):179–199
Hölzel BK, Ott U, Hempel H, Hackl A, Wolf K, Stark R, Vaitl D (2007) Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. Neurosci Lett 421(1):16–21
Itoh M, Miyazaki H, Takahashi Y (1996) Imaging of mind using positron emission tomography. J Intl Soc Life Info Sci 14(1): 76–80
Jasper HH (1958) The ten-twenty electrode system of the International Federation. Electroenceph Clin Neurophysiol 10:371–375
Jensen O, Gelfand J, Kounios J, Lisman JE (2002) Oscillations in the alpha band (9–12 Hz) increase with memory load during retention in a short-term memory task. Cereb Cortex 12(8): 877–882
Jha AP, Krompinger J, Baime MJ (2007) Mindfulness training modifies subsystems of attention. Cogn Affect Behav Neurosci 7(2):109–119

Jovicich J, Peters RL, Koch C, Braun J, Chang L, Ernst T (2001) Brain areas specific for attentional load in a motion-tracking task. J Cogn Neurosci 13(8):1048–1058

Kabat-Zinn J (1982) An outpatient program in behavioral medicine for chronic pain patients based on the practice of mindfulness meditation: theoretical considerations and preliminary results. Gen Hosp Psychiatry 4(1):33–47

Kasamatsu A, Hirai T (1966) An electroencephalographic study on the Zen meditation (Zazen). Folia Psychiatrica et Neurologica Japonica 20:315–336

Kihlstrom JF, Beer JS, Klein SB (2003) Self and identity as memory. In: Leary MR, Tangney J (eds) Handbook of self and identity. Guilford Press, New York, pp 68–90

Kisley MA, Cornwell ZM (2006) Gamma and beta neural activity evoked during a sensory gating paradigm: effects of auditory, somatosensory and cross-modal stimulation. Clin Neurophysiol 117(11):2549–2563

Klimesch W (1999) EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev 29(2–3):169–195

Kubicki S, Herrmann WM, Fichte K, Freund G (1979) Reflections on the topics: EEG frequency bands and regulation of vigilance. Pharmacopsychiatry 12:237–245

Kübler A, Dixon V, Garavan H (2006) Automaticity and reestablishment of executive control-an fMRI study. J Cogn Neurosci 18(8):1331–1342

Lagopoulos J, Xu J, Rasmussen I, Vik A, Malhi GS, Eliassen CF, Arntsen IE, Saether JG, Hollup S, Holen A, Davanger S, Ellingsen Ø (2009) Increased theta and alpha EEG activity during nondirective meditation. J Altern Complem Med 15(11):1187–1192

Lavallee CF, Hunter MD, Persinger MA (2011) Intracerebral source generators characterizing concentrative meditation. Cogn Process 12(2):141–150

Lee MS, Bae BH, Ryu H, Sohn JH, Kim SY, Chung HT (1997) Changes in alpha wave and state anxiety during Chun Do Sun Bup Qi-training in trainees with open eyes. Am J Chinese Med 25:289–299

Lehmann D, Grass P, Meier B (1995) Spontaneous conscious covert cognition states and brain electric spectral states in canonical correlations. Int J Psychophysiol 19(1):41–52

Lehmann D, Faber PL, Achermann P, Jeanmonod D, Gianotti LRR, Pizzagalli D (2001) Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self. Psychiatr Res Neuroimaging 108(2):111–121

Lehmann D, Pascual-Marqui RD, Strik WK, Koenig T (2010) Core networks for visual-concrete and abstract thought content: a brain electric microstate analysis. Neuroimage 49(1):1073–1079

Lehmann D, Faber PL, Tei S, Pascual-Marqui RD, Milz P, Kochi K (2012) Reduced functional connectivity between cortical sources in five meditation traditions detected with lagged coherence using EEG tomography. Neuroimage 60:1574–1586

Lloyd D, Morrison I, Roberts N (2006) Role for human posterior parietal cortex in visual processing of aversive objects in peripersonal space. J Neurophysiol 95(1):205–214

Lopes da Silva F (1991) Neural mechanisms underlying brain waves: from neural membranes to networks. Electroenceph Clin Neurophysiol 79(2):81–93

Lou HC, Kjaer TW, Friberg L, Wildschiodtz G, Holm S, Nowak M (1999) A 15O-H2O PET study of meditation and the resting state of normal consciousness. Hum Brain Mapp 7(2):98–105

Luks TL, Simpson GV (2004) Preparatory deployment of attention to motion activates higher order motion-processing brain regions. Neuroimage 22:1515–1522

Lutz A, Greischar LL, Rawlings NB, Ricard M, Davidson RJ (2004) Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. Proc Natl Acad Sci USA 101(46):16369–16373

Lutz A, Slagter HA, Dunne JD, Davidson RJ (2008) Attention regulation and monitoring in meditation. Trends Cogn Sci 12:163–169

Makeig S, Inlow M (1993) Lapses in alertness: coherence of fluctuations in performance and EEG spectrum. Electroenceph Clin Neurophysiol 86(1):23–35

Mellet E, Tzourio N, Crivello F, Joliot M, Denis M, Mazoyer B (1996) Functional anatomy of spatial imagery generated from verbal instructions. J Neurosci 16:6504–6512

Mikulas WL (1990) Mindfulness, self-control, and personal growth. In: Kwee MGT (ed) Psychotherapy, meditation, and health. East West Publications, London, pp 151–164

Minegishi Y, Isotani T, Yoshimura M, Yamada K, Nishida K, Morita S, Saito Y, Irisawa S, Ichikawa M, Kinoshita T, Kihara H (2009) Spatial brain electric activity changes after Kakurin-qigong. In: Kobayashi T, Ozaki I, Nagata K (eds) Brain topography and multimodal imaging. Kyoto University Press, Kyoto, pp 107–108

Mulert C, Jäger L, Schmitt R, Bussfeld P, Pogarell O, Möller HJ, Juckel G, Hegerl U (2004) Integration of fMRI and simultaneous EEG: towards a comprehensive understanding of localization and time-course of brain activity in target detection. Neuroimage 22:83–94

Murata T, Koshino Y, Omori M, Murata I, Nishio M, Sakamoto K, Horie T, Isaki K (1994) Quantitative EEG Study on Zen Meditation (Zazen). Jpn J Psychiat Neurol 48(4):881–890

Newberg AB, Iversen J (2003) The neural basis of the complex mental task of meditation: neurotransmitter and neurochemical considerations. Med Hypotheses 61(2):282–291

Newberg A, Alavi A, Baime M, Pourdehnad M, Santanna J, d'Aquili E (2001) The measurement of regional cerebral blood flow during the complex cognitive task of meditation: a preliminary SPECT study. Psychiatry Res 106(2):113–122

Nichols TE, Holmes AP (2002) Nonparametric permutation tests for functional neuroimaging: a primer with examples. Hum Brain Mapp 15:1–25

Niedermeyer E, Lopes da Silva F (2005) Electroencephalography: basic principles, clinical applications, and related fields, 5th edn. Lippincott Williams Wilkins, Philadelphia

Okuda J, Fujii T, Yamadori A, Kawashima R, Tsukiura T, Ohtake H, Fukatsu R, Suzuki K, Itoh M, Fukuda H (2000) Retention of words in long-term memory: a functional neuroanatomical study with PET. NeuroReport 11(2):323–328

Palva S, Palva JM (2007) New vistas for alpha-frequency band oscillations. Trends Neurosci 30(4):150–158

Pan W, Zhang L, Xia Y (1994) The difference in EEG theta waves between concentrative and non-concentrative Qigong states—a power spectrum and topographic mapping study. J Trad Chin Med 14(3):212–218

Pascual-Marqui RD (2002) Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. Methods Find Exp Clin Pharmacol 24(Suppl D):5–12

Pascual-Marqui RD, Michel CM, Lehmann D (1994) Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain. Int J Psychophysiol 18(1):49–65

Pascual-Marqui RD, Lehmann D, Koenig T, Kochi K, Merlo MC, Hell D, Koukkou M (1999) Low resolution brain electromagnetic tomography (LORETA) functional imaging in acute, neuroleptic-naive, first-episode, productive schizophrenia. Psychiatry Res 90(3):169–179

Pascual-Marqui RD, Esslen M, Kochi K, Lehmann D (2002) Functional imaging with low-resolution brain electromagnetic

tomography (LORETA): a review. Method Find Exp Clin Pharmacol 24(Suppl C):91–95
Peng CK, Henry IC, Mietus JE, Hausdorff JM, Khalsa G, Benson H, Goldberger AL (2004) Heart rate dynamics during three forms of meditation. Int J Cardiol 95(1):19–27
Perlman DM, Salomons TV, Davidson RJ, Lutz A (2010) Differential effects on pain intensity and unpleasantness of two meditation practices. Emotion 10(1):65–71
Piron H (2003) Meditation depth, mental health, and personal development. J Meditat Meditat Res 3:45–58
Qin Z, Jin Y, Lin S, Hermanowicz NS (2009) A forty-five year follow-up EEG study of Qigong practice. Int J Neurosci 119(4):538–552
Raffone A, Srinivasan N (2010) The exploration of meditation in the neuroscience of attention and consciousness. Cogn Process 11(1):1–7
Ranganath C, Johnson MK, D'Esposito M (2003) Prefrontal activity associated with working memory and episodic long-term memory. Neuropsychologia 41(3):378–389
Ray WJ, Cole HW (1985) EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. Science 228:750–752
Reverberi C, Cherubini P, Rapisarda A, Rigamonti E, Caltagirone C, Frackowiak RS, Macaluso E, Paulesu E (2007) Neural basis of generation of conclusions in elementary deduction. Neuroimage 38(4):752–762
Ruby P, Decety J (2004) How would you feel versus how do you think she would feel? A neuroimaging study of perspective-taking with social emotions. J Cogn Neurosci 16(6):988–999
Sarazin M, Pillon B, Giannakopoulos P, Rancurel G, Samson Y, Dubois B (1998) Clinicometabolic dissociation of cognitive functions and social behavior in frontal lobe lesions. Neurology 51(1):142–148
Snyder LH, Batista AP, Andersen RA (1997) Coding of intention in the posterior parietal cortex. Nature 386:167–170
Sun F, Wang J, Liu G, Jiao X, Zhang Z, Shi Y, Zhang T (1984) An analysis on EEG power spectrum and coherence during quiet state in QiGong. Acta Psychologica Sinica 17(4):76–81
Tallon-Baudry C, Bertrand O (1999) Oscillatory gamma activity in humans and its role in object representation. Trends Cogn Sci 3(4):151–162
Tart CT (1969) Altered states of consciousness. Wiley, New York
Tebecis AK (1975) A controlled study of the EEG during transcendental meditation: comparison with hypnosis. Folia Psychiatr Neurol Jpn 29(4):305–313
Tei S, Faber PL, Lehmann D, Tsujiuchi T, Kumano H, Pascual-Marqui RD, Gianotti LR, Kochi K (2009) Meditators and non-meditators: EEG source imaging during resting. Brain Topogr 22(3):158–165
Travis F (2001) Autonomic and EEG patterns distinguish Transcending from other experiences during transcendental Meditation practice. Int J Psychophysiol 42:1–9
Travis F (2011) Comparison of coherence, amplitude, and eLORETA patterns during Transcendental Meditation and TM-Sidhi practice. Int J Psychophysiol 81(3):198–202
Travis F, Arenander A (2006) Cross-sectional and longitudinal study of effects of transcendental meditation practice on interhemispheric frontal asymmetry and frontal coherence. Int J Neurosci 116(12):1519–1538
Travis F, Shear J (2010) Focused attention, open monitoring and automatic selftranscending: Categories to organize meditations from Vedic, Buddhist and Chinese traditions. Conscious Cogn 19:1110–1118
Travis F, Haaga DA, Hagelin J, Tanner M, Arenander A, Nidich S, Gaylord-King C, Grosswald S, Rainforth M, Schneider RH (2010) A self-referential default brain state: patterns of coherence, power, and eLORETA sources during eyes-closed rest and Transcendental Meditation practice. Cogn Process 11(1):21–30
Tuladhar AM, ter Huurne N, Schoffelen JM, Maris E, Oostenveld R, Jensen O (2007) Parieto-occipital sources account for the increase in alpha activity with working memory load. Hum Brain Mapp 28:785–792
Tulving E, Kapur S, Markowitsch HJ, Craik FI, Habib R, Houle S (1994) Neuroanatomical correlates of retrieval in episodic memory: auditory sentence recognition. Proc Natl Acad Sci USA 91(6):2012–2015
Vaitl D, Birbaumer N, Gruzelier J, Jamieson G, Kotchoubey B, Kübler A, Lehmann D, Miltner WHR, Ott U, Pütz P, Sammer G, Strauch I, Strehl U, Wackermann J, Weiss T (ASC Consortium) (2005) Psychobiology of altered states of consciousness. Psychol Bull 131(1):98–127
Vitacco D, Brandeis D, Pascual-Marqui R, Martin E (2002) Correspondence of event-related potential tomography and functional magnetic resonance imaging during language processing. Hum Brain Mapp 17:4–12
Wallace RK, Benson H, Wilson AF (1971) A wakeful hypometabolic physiologic state. Am J Physiol 221(3):795–799
Wang DJ, Rao H, Korczykowski M, Wintering N, Pluta J, Khalsa DS, Newberg AB (2011) Cerebral blood flow changes associated with different meditation practices and perceived depth of meditation. Psychiatry Res 191(1):60–67
Worrell GA, Lagerlund TD, Sharbrough FW, Brinkmann BH, Busacker NE, Cicora KM, O'Brien TJ (2000) Localization of the epileptic focus by Low-Resolution Electromagnetic Tomography in patients with a lesion demonstrated by MRI. Brain Topogr 12:273–282
Wrobel A (2000) Beta activity: a carrier for visual attention. Acta Neurobiol Exp (Warsz) 60(2):247–260
Yang SH, Yang QF, Shi JM (1994) Observation of electroencephalogram spectrum changes over one year of Qigong training. [Article in Chinese, Abstract in English] Zhongguo Zhong Xi Yi Jie He Za Zhi 14(11):643–646
Yang L, Wilke C, Brinkmann B, Worrell GA, He B (2011) Dynamic imaging of ictal oscillations using non-invasive high-resolution EEG. Neuroimage 56(4):1908–1917
Yuasa Y (1990) Ki to ningen kagaku: Nitchu shinpojumu koenshu (Qi and human science; in Japanese). Hiraga Publishing, Tokyo 361 pp
Zeidan F, Johnson SK, Gordon NS, Goolkasian P (2010) Effects of brief and sham mindfulness meditation on mood and cardiovascular variables. J Altern Complem Med 16:867–873
Zhang J-Z, Zhao J, He Q-N (1988) EEG findings during special psychical state (Qi Gong state) by means of compressed spectral array and topographic mapping. Comput Biol Med 18(6):455–463
Zumsteg D, Wennberg RA, Treyer V, Buck A, Wieser HG (2005) H2(15)O or 13NH3 PET and electromagnetic tomography (LORETA) during partial status epilepticus. Neurology 65:1657–1660
Zumsteg D, Friedman A, Wieser HG, Wennberg RA (2006a) Propagation of interictal discharges in temporal lobe epilepsy: correlation of spatiotemporal mapping with intracranial foramen ovale electrode recordings. Clin Neurophysiol 117:2615–2626
Zumsteg D, Lozano AM, Wennberg RA (2006b) Depth electrode recorded cerebral responses with deep brain stimulation of the anterior thalamus for epilepsy. Clin Neurophysiol 117:1602–1609
Zysset S, Huber O, Ferstl E, von Cramon DY (2002) The anterior frontomedian cortex and evaluative judgment: an fMRI study. Neuroimage 15(4):983–991